

ON THE PRINCIPAL MAGNETIC SUSCEPTIBILITIES
OF CRYSTALS

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ABSTRACT

A new method of measuring the principal magnetic susceptibilities of crystals.—The crystal to be measured is immersed in a solution, the susceptibility of which is varied, and the orientation of the crystal adjusted till there is no movement of the crystal due to the magnetic field. The susceptibilities of the solutions are then measured. From these values the principal susceptibilities can then be easily obtained. The method does not require any preparation of crystal sections, measurement of the magnetic field or gradient of the field. The range of application of this method is for volume susceptibilities of -0.9×10^{-6} to $+70 \times 10^{-6}$.

The principal magnetic susceptibilities of certain crystals.—The above method is applied to the measurement of principal susceptibilities of 14 crystals. Of these eleven are paramagnetic, and belong to the monoclinic double sulphate hexahydrate isomorphous series, $\text{MeSO}_4 \cdot \text{R}_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$. With these crystals the results seem to indicate that, unlike the optical and crystallographic properties, the principal susceptibilities and their relative magnitudes depend almost entirely on the paramagnetic ion alone. The influence of the alkali or ammonium ion is secondary. In the series containing copper the greatest difference in maximum and minimum susceptibilities is 28% of the average susceptibility, in the nickel series 4%, in the Co series 32%, in the Fe series 16% and in the Mn series 1%. Of the diamagnetic crystals, NaNO_3 and KNO_3 , which are similar in their crystallographic properties to calcite and aragonite respectively, show similar magnetic properties.

THIS paper presents an experimental study of the principal magnetic susceptibilities of a series of chemically and crystallographically related crystalline compounds. The method involves the obtaining of solutions with the same susceptibilities as the crystal in definite known directions, and the measurement of the susceptibility of these solutions.

HISTORICAL

Measurements of the principal magnetic susceptibilities of crystals have been attempted by a number of investigators since the early qualitative work of Tyndall. Voigt and Kinoshita¹ measured a number of para- and diamagnetic crystals. Finke² in the same laboratory did some work on the well known monoclinic isomorphous series of double sulphates $\text{MeSO}_4\text{R}_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$. More recently Jackson³ and Foex⁴

¹ Voigt and Kinoshita, *Ann. der Physik* **24**, 492 (1907).

² Finke, *Ann. d. Physik* **31**, 149 (1910).

³ Jackson, *Phil. Trans. R. S. A.* **224**, 1 (1923); *R. S. Proc., A*, **104**, 671 (1923).

⁴ Foex, *Ann. d. Physique* **16**, 174 (1921).

have made measurements of paramagnetic crystals over great temperature ranges.

The experimental procedure in these attempts was to cut definite sections out of the crystal and to measure the force or torque on these sections. With a knowledge of the field and its gradient the susceptibilities could then be calculated. Another way was to compare the force or torque with that on a standard substance of the same dimensions.

It is evident that there exist in these methods many possibilities of error incident to the measuring of the field, the gradient of the field, the preparation of the crystal sections, the placing of the crystal in the field (especially in view of the great attraction toward the pole pieces in the case of strongly paramagnetic substances), the difference in various sections due to the non-homogeneity of the crystal, etc. In the present

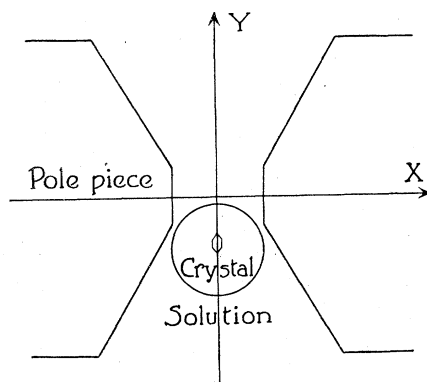


Fig. 1. Placing of crystal as seen from above.

investigation the aim has been to eliminate as far as possible these sources of error.

METHOD

The crystal is suspended vertically in the non-homogeneous field of a Weiss magnet as shown in Figs. 1 and 2. The suspension is a glass thread sufficiently thick to prevent any detectable turning of the crystal due to the action of the field. The thread is attached to a graduated head, giving the possibility of rotating the crystal. The crystal is first attached (with proper regard to orientation) to a fine glass thread about 10 cm long by means of the smallest possible amount of molten shellac. This thread in turn is attached to the rest of the suspension, the whole being about 75 cm long. The suspension is arranged symmetrically between the pole pieces (as shown in the diagrams), and the orientation

of the crystal about the axis of suspension is made definite by sending a narrow beam of light along the Y -axis and reflecting it back from a known face of the crystal. This together with the crystallographic data makes the orientation of the crystal completely known.

The crystal is suspended in a solution the susceptibility of which can be varied in the range of susceptibilities of the crystal. The container is pictured in the diagram. The arrangement makes it possible for the solution to be drawn out into another vessel and its susceptibility changed by the addition of other substances. Since all the crystals used in this research were water soluble, the solutions were first made saturated with respect to the material of the crystal used. This effectively prevented the dissolving of any of the crystals during the course of a run.

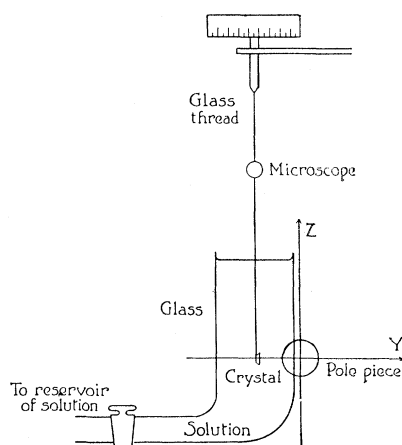


Fig. 2. Side-view of the crystal and suspension.

With substances the susceptibility of which is greater than that of water, the susceptibility of the solution is raised when necessary by the addition of a solution concentrated with respect to $MnCl_2$ and saturated with respect to the substance to be measured. The susceptibility is lowered by adding a solution saturated with respect to the substance. With materials of lower susceptibilities than water the susceptibility is lowered by adding a concentrated potassium iodide solution (saturated as above described) and raised by the addition of saturated solution.

The crystals were prepared from C.P. chemicals by the method described by Tutton.⁵ Only well formed crystals were used. The best size is about 3 to 4 mm thick and about the same in other dimensions.

⁵ Tutton, *Crystallography and Practical Crystal Measurement*, p. 14.

A movement of the crystal along the Y -axis is observed by means of the microscope. Motion along the X -axis is also observed. By means of the graduated head the crystal is adjusted till there is no movement along the X -axis when the field is turned on. The concentration of the solution is then varied till the field causes no motion along the Y -axis. The angles are read and a sample of the solution is drawn out. The crystal is then rotated through 90° when another position of zero movement along the X -axis is found. The susceptibility of the solution is then adjusted till there is no movement along the Y -axis, and another sample is taken. The crystal is then rehung so as to rotate about another axis and the same process is repeated.

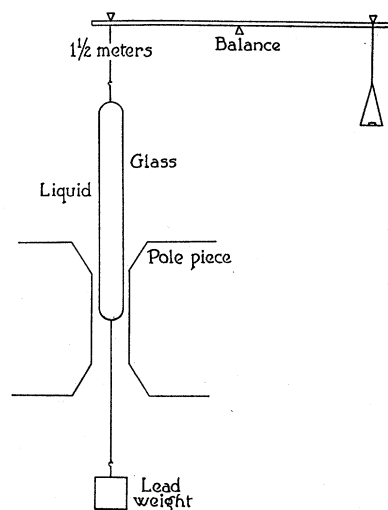


Fig. 3.

The susceptibility of the solution is measured⁶ by suspending a long glass tube (about 1 cm in diameter), filled with the solution, in the field of the magnet. Large pole pieces are used to secure a uniform field at the lower end of the tube. The tube is made long enough for the field at the upper end to be negligible. A lead weight is suspended from the lower end of the tube by means of silk thread. The weight is not necessary for weakly magnetic solutions. For strongly magnetic solutions the weight prevents the tube from going over to the pole piece. The glass for the tube is so chosen that the force of the field on the whole suspension without liquid is as small as possible. The force of the field is measured by means of a sensitive balance placed high enough to be

⁶ A. P. Wills, Phys. Rev. **6**, 223 (1898).

away from the influence of the field. The net force on the liquid is compared to the net force on the same tube filled with pure water. Correcting for the susceptibility of the air, the two forces are to each other as the susceptibilities. The value of the susceptibility of water is taken as⁷ -0.720×10^{-6} . The field strength of the magnet is maintained constant throughout this part of the determination but its value need not be known.

THEORY OF THE METHOD

In general, when a substance is introduced into a magnetic field it will be polarized magnetically. The effect of this polarization will be to modify the magnetic intensity, which had previously existed, both in magnitude and direction. However, if the induced magnetization is small compared with the magnetic intensity this effect, for the purpose of this investigation, can be considered as negligible.⁸ The magnetic intensity will therefore be considered as unaltered by the introduction of the substance.

From the above and from the well known theorems of magneto-statics it follows that the force per unit volume which will be exerted on a weakly magnetic substance suspended in a magnetic field and surrounded by a solution will be;

$$\begin{aligned} F_x &= I_x \partial H_x / \partial x + I_y \partial H_x / \partial y + I_z \partial H_x / \partial z \\ &\quad - K_s [H_x \partial H_x / \partial x + \partial H_x / \partial y + \partial H_x / \partial z] \\ F_y &= I_x \partial H_y / \partial x + I_y \partial H_y / \partial y + I_z \partial H_y / \partial z \\ &\quad - K_s [H_x \partial H_y / \partial x + \partial H_y / \partial y + \partial H_y / \partial z] \\ F_z &= I_x \partial H_z / \partial x + I_y \partial H_z / \partial y + I_z \partial H_z / \partial z \\ &\quad - K_s [H_x \partial H_z / \partial x + H_y \partial H_z / \partial y + H_z \partial H_z / \partial z] \end{aligned} \quad (1)$$

where H is the magnetic intensity, I is the induced magnetic moment per unit volume or the intensity of magnetization, K_s is the susceptibility of the solution. There will be, in addition, surface traction on the interface of solid and solution of $(2\pi I_{n_1}^2 - 2\pi I_{n_2}^2)$ ⁹ per unit area. Since in these cases I_n is very small compared to the gradient of H these tractions are unimportant.

With respect to a system of axes XYZ fixed in the magnet, as shown in Figs. 1 and 2, it is evident from the symmetry of the field, and the vanishing of the curl and divergence of H , that when the substance is situated in the Y axis,

$$H_y = H_z = \partial H_y / \partial z = \partial H_z / \partial y = \partial H_z / \partial x = \partial H_x / \partial z = 0$$

⁷ A. P. Wills, Phys. Rev. 20, 188 (1905).

⁸ Maxwell, Electricity and Magnetism, 3rd Ed., pp. 69 and 73.

⁹ Larmor, Phil. Trans. R. S. A. 190, 248 (1897).

Eq. (1) can then be written,

$$F_x = I_y \partial H_x / \partial y, F_y = I_x \partial H_x / \partial y - K_s H_x \partial H_x / \partial y, F_z = 0 \quad (2)$$

In general for crystalline media, when there is no ferromagnetism it has been found by experiment that I is a linear vector function of H . Referred to an arbitrary set of axes $X'Y'Z'$ fixed in the crystal we have

$$\begin{aligned} I_{x_1} &= k_{11}H_{x_1} + k_{12}H_{y_1} + k_{13}H_{z_1} \\ I_{y_1} &= k_{21}H_{x_1} + k_{22}H_{y_1} + k_{23}H_{z_1} \\ I_{z_1} &= k_{31}H_{x_1} + k_{32}H_{y_1} + k_{33}H_{z_1} \end{aligned} \quad (3)$$

The k 's are the constant coefficients of magnetization. In general I will not have the same direction as H . However, there are three mutually perpendicular directions in which I and H will have the same direction. If we choose a set of axes $X''Y''Z''$ parallel to these directions, we have

$$I_{x''} = K_1 H_{x''}, I_{y''} = K_2 H_{y''}, I_{z''} = K_3 H_{z''}$$

These K 's are the principal susceptibilities and the corresponding system of axes are the principal magnetic axis. The principal axes and susceptibilities (K) can be found in terms of the "coefficients of magnetization" (k), from the theory of the linear vector function¹⁰. The problem now resolves itself into a determination of the six k 's ($k_{1m} = k_{m1}$)

Referred to XYZ fixed in the magnet let the direction cosines of X' be l_1, m_1, n_1 ; of Y' , l_2, m_2, n_2 ; and of Z' , l_3, m_3, n_3 . We then have

$$I_x = l_1 I_{x_1} + l_2 I_{y_1} + l_3 I_{z_1}, I_y = m_1 I_{x_1} + m_2 I_{y_1} + m_3 I_{z_1} \quad (4)$$

If the crystal is suspended with the Z' -axis parallel to the Z -axis and θ is the angle which the X' -axis makes with X it follows from Eqs. (3) and (4)

$$I_x / H_x = \frac{1}{2}(k_{11} + k_{22}) + \frac{1}{2}(k_{11} - k_{22}) \cos 2\theta - k_{12} \sin 2\theta \quad (5)$$

$$I_y / H_x = \frac{1}{2}(k_{11} - k_{22}) \sin 2\theta + k_{12} \cos 2\theta \quad (6)$$

For F_x to vanish it is evident from Eqs. (2), (5) and (6), that the right hand side of Eq. (6) must vanish yielding

$$\tan 2\theta = -2k_{12} / k_{11} - k_{22} \quad (7)$$

For F_y to vanish we must have by Eqs. (2) and (5)

$$I_x / H_x = K_s \quad (8)$$

In order that both F_x and F_y vanish simultaneously the conditions given by Eqs. (7) and (8) must both be fulfilled. It is evident from Eq. (5) that the values of θ imposed by Eq. (7) makes I_x either a maximum or a minimum, since the derivative of I_x with respect to θ is equal to $-I_y$. These values of θ recur at intervals of 90° in θ .

Let a_1 and a_2 respectively be the susceptibilities of the solutions necessary to bring about a balance in the maximum and minimum positions, and let θ_1 be the angle which the X' makes with the X -axis in

¹⁰ Gibbs-Wilson, Vector Analysis.

the maximum position when the crystal is suspended with the Z' -axis parallel to Z . It then follows from Eqs. (5), (7) and (8), after some algebraic manipulation that;

$$\begin{aligned} k_{11} &= \frac{1}{2}[a_1 + a_2 + (a_1 - a_2)\cos 2\theta_1]; & k_{22} &= \frac{1}{2}[a_1 + a_2 - (a_1 - a_2)\cos 2\theta_1]; \\ k_{12} &= -\frac{1}{2}(a_1 - a_2)\sin 2\theta_1 \end{aligned} \quad (9)$$

Similarly let a_3, a_4, θ_2 be the corresponding values when Y is parallel to the axis of suspension and likewise a_5 and a_6 when X is parallel to Z the angle of suspension and θ is the angle between X and Y at a maximum position. By a procedure similar to the obtaining of Eqs. (5), (6), (7), (8) and (9) we have;

$$\begin{aligned} k_{33} &= \frac{1}{2}[a_3 + a_4 - (a_3 - a_4)\cos 2\theta_2] \\ k_{23} &= -\frac{1}{2}(a_5 - a_6)\sin 2\theta_3, & k_{13} &= \frac{1}{2}(a_3 - a_4)\sin 2\theta_2 \end{aligned} \quad (10)$$

and also;

$$\begin{aligned} k_{11} &= \frac{1}{2}[a_3 + a_4 + (a_3 - a_4)\cos 2\theta_2] \\ k_{22} &= \frac{1}{2}[a_5 + a_6 + (a_5 - a_6)\cos 2\theta_3] \\ k_{33} &= \frac{1}{2}[a_5 + a_6 - (a_5 - a_6)\cos 2\theta_3] \end{aligned} \quad (11)$$

Eqs. (9) and (10) give the k 's in terms of the a 's and O 's. There are six equations to determine the six k 's. We have in addition Eq. 11 which gives us three independent values of k_{11} , k_{22} , and k_{33} . These can be averaged with the values obtained in Eqs. (9) and (10).

If the directions of the three principal magnetic axes are known, then the susceptibility of the solutions obtained by setting the crystal parallel to each of these axes in turn are the principal susceptibilities. If the position of one principal axis is known, the method is considerably simplified, since the other two axes are in the plane perpendicular to this direction.

We choose a set of co-ordinate axes in the crystal, with the Z -axis parallel to the known direction, suspending the crystal about this axis we determine a_1, a_2 and θ_1 as before. Setting the Z -axis parallel to H we determine a_3 . It is also well, but not necessary to determine a_4 in the perpendicular direction. It can be shown that;

$$K_1 = a_1, \quad K_2 = a_2, \quad K_3 = a_3 \quad (12)$$

where the K 's are the principal susceptibilities. The angle which the principal axis of maximum susceptibility in the XY plane makes with the X -axis in the crystal is $-\theta_1$. As a check on these results we have;

$$K_1 \cos^2 \theta_1 + K_2 \sin^2 \theta_1 = a_4 \quad (13)$$

The orientations and magnitudes of the magnetic axes are completely given by Eqs. (12).

If the crystal be isotropic, it is evident from Eq. (2) that when the concentration of the solution is adjusted so that the force vanishes, the susceptibility of the solution is equal to that of the crystal.

THE CRYSTALS

The crystals used were;

$\text{Cu}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$	$\text{Co}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$
$\text{CuK}_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$	$\text{CoK}_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$
$\text{CuRb}_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$	$\text{CoRb}_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$
$\text{Ni}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$	$\text{Mn}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$
$\text{NiK}_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$	$\text{FeK}_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$
$\text{NiRb}_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$	$\text{NaNO}_3, \text{KNO}_3, \text{Sr}(\text{NO}_3)_2$

All except the last three are paramagnetic and belong to the well known isomorphous series. Tutton¹¹ in a series of elaborate investigations has shown that members of this series differ from each other

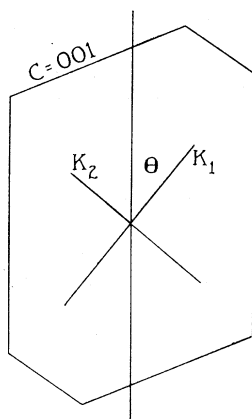


Fig. 4. Plane of symmetry of the double sulphate crystals.

only very slightly with regard to axial ratio, interfacial angles and refractive index. It is significant however that the above mentioned quantities show smaller changes when, for example, Co is substituted for Ni than when one alkali is substituted for another, or for an NH_4 group.

Of the diamagnetic crystals NaNO_3 , KNO_3 , $\text{Sr}(\text{NO}_3)_2$ the first two are of interest since their structures are very similar to that of calcite and aragonite already investigated by Voigt and Kinoshita.

With the monoclinic crystals the assumption was made that one of the principal magnetic axes lies in the axis of symmetry. Physically this means that in this direction the magnetization is parallel to the field, or in our notation I_y must vanish in all cases when this axis is parallel to H .

¹¹ Tutton, Proc. R. S. London **88**, 361 (1913); Trans. R. S. A. **216**, 1 (1916).

The above assumption was found to hold true in every case within the limit of error. Eqs. (9) were then used rather than (8). After a balance between solution and crystal was obtained the field was varied within wide limits, to ascertain whether there existed a dependence on field strength. None was found. This shows that it is very unlikely that any ferromagnetism exists in these crystals.

ACCURACY OF RESULTS

Because of surface forces where the glass thread emerges into the air, the pendulum cannot show differences in susceptibility much less than 10^{-8} . Very good checks have been obtained with that order of magnitude. Using the balance to measure the susceptibility of the liquid entails weighing to 0.5 mg, which is easily possible. However the percentage precision, as regards absolute values, is limited by our knowledge of the susceptibility of water. This is probably not known to better than 0.5 percent.

The fact that the suspension of the crystal has a different susceptibility from that of the crystal leads to a systematic fractional error roughly equal to the ratio of the volume of the suspension in the strong part of the field to the volume of the crystal. By a proper choice of thickness of thread this can be reduced to less than 0.2 percent.

The error due to the finite size of the crystal is unimportant. However there is an accidental error which arises from the fact that the crystal may not have its center of mass in the YZ plane. This error is reduced by suspending the crystal in that part of the field in which the gradient is small. This error does not appreciably affect the values of the a 's (Eq. 11) but may affect the value of the angles to the extent of about 2° . Since the value of the angle is obtained from four readings, two maxima and two minima each 180° apart, this error is practically balanced out.

In comparing these results for the double sulphates with those measured by Finke² and Jackson³, we find a very considerable disagreement. However the average mean value of the three principal susceptibilities of these measurements on the Co and Ni double sulphates agrees very well with a measurement by Jackson on the same crystals powdered. Finke's mean values do not so agree. Furthermore the consistency of these results as shown by Table I is a very good indication of their accuracy.

The average diamagnetic results are slightly lower than the values found from measurements in solution. This is another illustration of

the general phenomenon observed by Oxley,¹² a diminution of diamagnetic susceptibility on crystallization.

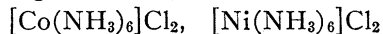
RESULTS AND DISCUSSION

Table I gives the results of the measurements of the double sulphate series. It is significant that while the Ni, Co and Fe salts have large differences in their principal susceptibilities, the Ni and Mn salts, though of almost identical crystal structure have only small differences in their principal susceptibilities. This would perhaps be explicable on the theory suggested by Foex⁴ that due to the forces of crystalline nature, there exists a potential energy which is a function of the direction. The direction of maximum susceptibility would then be the direction of minimum potential energy.

In view of the aforementioned similarities in the crystal structure of this series and the fact that smallest differences in refractive index, interfacial angle, and axial ratio are produced by varying the paramagnetic ion, it is difficult to concede that forces of a crystalline nature are responsible for these differences. In this connection it is interesting to note that rhombic $\text{NiSO}_4 \cdot 7\text{H}_2\text{O}$ has small differences in the principal susceptibilities, while in $\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$, which is also rhombic, the differences are large. By Werner's coordination theory six molecules of water of crystallization are associated with the Co ion especially, and the seventh, with the SO_4 ion. The double sulphate is to be considered as a replacement of the water of crystallization by the alkali sulphate.

It is somewhat plausible that an ion with a spherical symmetrical external field would be free to rotate within its shell of H_2O molecules, whereas a departure from this symmetry would introduce forces opposing this rotation. On these considerations the differences in susceptibility would be ascribed to the assymetry of the external field of the paramagnetic ion.

It would be interesting, in this connection, to examine crystals like



which are cubic, and the lattice structure of which is known, for differences of susceptibility in different directions. According to these views we should get differences similar to those found in the double sulphates.

The Weiss¹³ magneton numbers show very considerable deviations from whole numbers. As for the Bohr magneton numbers, it is difficult to decide from these data which computation is preferable; that is

¹² Oxley, Phil. Trans. R. S. A. **214**, 109 (1914).

¹³ Weiss, Phys. Zeits. **12**, 935 (1911).

TABLE I

Results of the measurements on the double sulphate series.

Axes 1 and 2 refer respectively to the maximum and minimum principal susceptibilities in the plane of symmetry of the crystal; axis 3 refers to the principal susceptibility perpendicular to the plane. The angle θ is the angle which the axis of maximum susceptibility in the plane of symmetry, makes with the C crystallographic axis; ϕ is the angle which the maximum refractive index, in the same plane, makes with the same axis. K is the volume susceptibility, χ is the mass susceptibility, χ_m the molecular susceptibility, χ_m' the molecular susceptibility with correction for diamagnetism. The quantity n is the number of Weiss magnetons, n' is the number of Bohr magnetons found by dividing n by 5, and n'' is the number of Bohr magnetons calculated according to Pauli-Sommerfeld, taking into account space quantization. The temperature is 27°C.

Compound	Axis	θ	ϕ	$K \times 10^6$	$\chi \times 10^6$	$\chi_m \times 10^6$	$\chi_m' \times 10^6$	n	n'	n''
Cu(NH ₄) ₂ (SO ₄) ₂ · 6H ₂ O	1			6.80	3.52	1396	1550	9.48		
	2	-74°	-72°	5.40	2.80	1112	1260	8.54	2	1
	3			6.62	3.44	1364	1515	9.42		
CuK ₂ (SO ₄) ₂ · 6H ₂ O	1			7.52	3.37	1478	1625	9.75		
	2	-99°	-162°	5.62	2.52	1104	1250	8.55	2	1
	3			6.83	3.12	1342	1490	9.34		
CuRb ₂ (SO ₄) ₂ · 6H ₂ O	1			6.97	2.72	1437	1590	9.63		
	2	-76°	-64°	5.44	2.11	1122	1270	8.62	2	1
	3			6.78	2.63	1400	1550	9.52		
Ni(NH ₄) ₂ (SO ₄) ₂ 6H ₂ O	1			20.2	10.5	4120	4270	15.8		
	2	-7°	-81°	19.9	10.35	4060	4210	15.7	3	2
	3			20.0	10.4	4080	4230	15.8		
NiK ₂ (SO ₄) ₂ · 6H ₂ O	1			20.5	9.16	3980	4130	15.5		
	2	-17°	-84°	19.7	8.80	3820	3970	15.2	3	2
	3			19.6	8.76	3800	3950	15.2		
NiRb ₂ (SO ₄) ₂ · 6H ₂ O	1			20.2	7.81	4110	4260	15.8		
	2	-19°	-77°	19.5	7.54	3970	4120	15.5	3	2
	3			19.6	7.58	3990	4140	15.6		
Co(NH ₄) ₂ (SO ₄) ₂ · 6H ₂ O	1			56.2	29.6	11610	11760	26.2		
	2	-13°	-80°	40.7	21.4	8410	8560	22.4	5	4
	3			48.9	25.7	10120	10270	24.5		
CoK ₂ (SO ₄) ₂ · 6H ₂ O	1			57.6	25.9	11270	11420	25.9		
	2	-44°	-84°	44.6	20.1	8720	8870	22.8	5	4
	3			48.6	21.9	9510	9660	23.8		
CoRb ₂ (SO ₄) ₂ · 6H ₂ O	1			56.3	22.0	11540	11690	26.1		
	2	-25°	-74°	42.9	16.7	8790	8940	22.9	5	4
	3			49.0	19.1	10040	10190	24.4		
FeK ₂ (SO ₄) ₂ · 6H ₂ O	1			59.8	27.5	11840	11990	26.4		
	2	55°	-78°	52.1	23.9	10320	10470	24.8	5	4
	3			61.4	28.4	12160	12310	26.8		
Mn(NH ₄) ₂ (SO ₄) ₂ · 6H ₂ O	1			62.8	34.3	13320	13470	28.1		
	2	14°	-83°	62.6	34.2	13280	13430	28.1	6	5
	3			63.1	34.5	13380	13530	28.1		

the assignment of one Bohr magneton for each five Weiss magnetons, or the Sommerfeld-Pauli¹⁴ method based on space quantization, which would give,¹⁵

¹⁴ Pauli, Phys. Zeits. **21**, 615 (1920); Epstein, Science **57**, 532 (1923); Gerlach, Phys. Zeits. **24**, 275 (1923); Sommerfeld, Phys. Zeits. **24**, 360 (1923).

¹⁵ Sommerfeld, Atombau and Spektrallinien, 4th Ed., p. 631.

Bohr magnetons: 1 2 3 4 5
 Weiss magnetons:¹⁶ 8.6 14.1 19.2 24.4 29.4

TABLE II

Compound	Crystal system	Axis	Volume susceptibility	Mass susceptibility	Molecular susceptibility	Average molecular susceptibility
			$K \times 10^6$	$\chi \times 10^6$	$\chi_m \times 10^6$	$\chi' \times 10^6$
NaNO ₃	trigonal	trig axis	-0.788	-0.347	-29.5	-25.9
		⊥ trig axis	-0.644	-0.284	-24.1	
CaCO ₃ (calcite)*	trigonal	trig axis	-1.10	-0.406	-40.7	-37.8
		⊥ trig axis	-0.98	-0.364	-36.4	
KNO ₃	rhombic	c axis	-0.744	-0.353	-35.6	-31.7
		b axis	-0.620	-0.294	-29.7	
		a axis	-0.624	-0.296	-29.9	
CaCO ₃ (aragonite)*	rhombic	c axis	-1.30	-0.444	-44.4	-40.8
		b axis	-1.14	-0.387	-38.7	
		a axis	-1.15	-0.392	-39.2 *	
Sr(NO ₃) ₂	cubic		-0.793	-0.271	-57.2	-57.2

*Voigt and Kinoshita loc. cit.

DIAMAGNETIC CRYSTALS

W. L. Bragg¹⁷ has recently published a theory accounting for the double refraction of calcite and aragonite on the basis of the mutual influence of the induced electric moments. This effect is specially great for the oxygen ions which lie close together, as shown by x-ray analysis. An attempt to explain the differences in diamagnetic susceptibility along the same lines shows that the internal field due to diamagnetic polarization is too small to account for the facts.

The writer wishes to express his thanks and appreciation to Professor A. P. Wills, under whose supervision this research was done, for his kind interest, suggestions and advice.

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 August 16, 1926.

¹⁶ In Table I, the Bohr magneton numbers are given to the nearest integer since it is not to be expected that they will fit any one of three principal susceptibilities, or their average.

¹⁷ Bragg, Proc. R. S. London **105**, 370 (1924).